

# The nature and extent of organisms in vessel sea-chests: A protected mechanism for marine bioinvasions

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## Abstract

A total of 150 different organisms, including one plant species and 12 animal phyla were identified from sea-chests of 42 vessels visiting or operating in New Zealand between May 2000 and November 2004. Forty-nine percent of organisms were sessile, 42% mobile adults and the remaining 9% sedentary. Decapods were the most represented group with 19 species present among 79% of vessels. Forty percent of organisms were indigenous to New Zealand, 15% introduced, 10% non-indigenous, and 35% of unknown origin. Sea-chests have the potential to (1) transfer non-indigenous organisms between countries across oceanic boundaries; and (2) disperse both indigenous and introduced organisms domestically. The occurrence of adult mobile organisms is particularly significant and indicates that sea-chests may be of greater importance than ballast water or hull fouling for dispersing certain marine species. These findings emphasise the need to assess and manage biosecurity risks for entire vessels rather than different mechanisms (i.e., ballast water, hull fouling, sea-chests, etc.) in isolation.

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## 1. Introduction

Human-mediated introductions of non-indigenous marine species (NIMS) into regions where they did not formally exist have had positive commercial and even ecological benefits (e.g., Galil, 2000; Sinner et al., 2000; Hayes and Sliwa, 2003; Wonhom et al., 2005). However, many of these organisms have resulted in adverse ecological, economic, and social consequences (Carlton, 1996, 2001; Pimentel et al., 2000; Hewitt, 2003). A variety of vectors are responsible for translocating NIMS around the world and along coastlines domestically, including shipping, fisheries, mariculture and the aquarium trade (e.g., Carlton, 1985, 1987, 1992; Cohen and Carlton, 1995;

Thresher et al., 1999; Ruiz et al., 2000; Minchin and Gollasch, 2002; Hewitt et al., 2004). However, international shipping is generally considered to be responsible for the majority of inadvertent NIMS introductions (Carlton, 1987; Cranfield et al., 1998; Minchin and Gollasch, 2002; Nehring, 2002).

A variety of shipping-related mechanisms are recognised, including ballast and bilge water discharges, hull fouling, sea-chests, sea-sieves, anchors, chain lockers, and piping (Schormann et al., 1990; Carlton, 1995; AMOG Consulting, 2002; Coutts et al., 2003). Of these, particular attention has been given to ballast water and hull fouling as key mechanisms, particularly for larval stages and adult sessile organisms (e.g., Carlton, 1995; Cranfield et al., 1998; Hewitt et al., 1999; Ruiz et al., 2000; Fofonoff et al., 2003). However, the importance of ballast water and hull fouling relative to other shipping-related mechanisms remains poorly understood. Furthermore, emerging evidence suggests that other mechanisms, in particular vessel sea-chests, may explain the global distribution of

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organisms for which transport via ballast water or hull fouling is questionable (Coutts et al., 2003).

Sea-chests are recesses built into a vessel's hull below the waterline that house the intake pipes for sea-water used for ballast, engine cooling and fire fighting. Anecdotal evidence and discussion of sea-chest systems as potential dispersal mechanisms for marine organisms has been recognised in the scientific literature for several decades (e.g., Newman, 1963; Hoese, 1973; Carlton, 1985; Slack-Smith and Brearly, 1987; Richards, 1990; Carlton, 1995; Cohen and Carlton, 1995; Carlton, 2001; AMOG Consulting, 2002; Davis and Davis, 2004). However, the potential for sea-chests to disperse NIMS was probably first highlighted when Coutts et al. (2003) documented the occurrence of two recognised pest species, the European clam *Corbula gibba* and the European green crab *Carcinus maenas*, inside the sea-chests of a passenger ferry in southern Australia. Despite such findings, a more comprehensive understanding of the potential for sea-chests to house and disperse aquatic organisms has not yet emerged. Therefore the aim of this study was to determine the nature and extent of organisms inside sea-chests of vessels in New Zealand and to establish their role as a dispersal mechanism for marine species.

## 2. Materials and methods

### 2.1. Characteristics of sea-chests

The size and number of sea-chests varies with vessel size and type. For example, a small 500 gross weight tonne (GWT) fishing vessel may only possess a single 0.5 m<sup>3</sup> sea-chest while a 30,000 GWT bulk carrier could have several sea-chests >2 m<sup>3</sup> in volume. Furthermore, most large vessels generally have an upper and lower sea-chest (Fig. 1). Each is covered with a flush fitting steel grille with either round holes 15–25 mm in diameter, or slots 20–35 mm wide by ~250 mm long. The grilles prevent large debris from entering the sea-chests during ballast pumping, although this does not preclude the entry of small marine organisms. Sea-sieves or strainers are located between the sea-chests and the pumps and are designed to retain objects >5 mm (Fig. 1). While sea-sieves are accessible from inside the vessel, sea-chests are normally only accessible from the outside of the vessel after the grilles are removed, usually during slipping or dry-docking.

### 2.2. Sample collection and processing

A total of 53 sea-chests were sampled from 42 vessels at three vessel maintenance facilities around New Zealand (Auckland, Nelson and Lyttelton) between May 2000 and November 2004. A questionnaire was used to obtain as much information as possible about each vessel (e.g., vessel size, vessel type, maintenance history, voyage history, etc.). Vessels sampled included fishing vessels (27); bulk carriers (3); research vessels (3); passenger ferries (2); and a cruise ship, cable layer, container, dredge, frigate, tanker and

tug boat ranging in size from 135 to 13,621 GWT. As many sea-chests were sampled from each vessel as possible prior to the commencement of maintenance work. Single sea-chests were sampled from 38 vessels, while four vessels had several sea-chests sampled. Vessels were sampled after an average in-service period (i.e., period of time between visiting vessel maintenance facilities) of 822 days. Twenty four vessels were classified as domestic (100% of their in-service period in New Zealand waters), nine semi-international (>75% of their in-service period outside New Zealand waters) and nine international (100% of their time outside New Zealand waters, but visited maintenance facilities in New Zealand at the completion of their in-service period). Thirteen of the vessels and their 20 associated sea-chests were retrofitted with sea-chest treatment systems (e.g., CHLOROPAC®, Cathelco, Chem-Free™, etc.) designed to reduce the accumulation of organisms.

To sample each sea-chest, a putty scraper was used to remove fouling attached to the internal surfaces and representative samples of all other organisms were collected by hand. All organisms >1 mm in size (dead and alive) were identified to the lowest taxonomic level practical. Organisms were classified as indigenous (an organism that originates in New Zealand); introduced (a foreign organism that has established in New Zealand); and non-indigenous (a foreign organism not previously recorded in New Zealand) according to Cranfield et al. (1998). Organisms only identified to genus level or higher were classified as unknown. Organisms were also classified as sessile (permanently attached to the substratum), sedentary (attached to the substratum but capable of limited movement), or mobile (capable of spontaneous movement).

### 2.3. Data processing and analysis

The PRIMER V5.2.2 software package was used for all statistical analyses. A species (taxa)-area curve analysis was undertaken to evaluate sampling effectiveness for vessels from the various geographical regions of operation (i.e., domestic, semi-international, international as described above). A Bray–Curtis similarity matrix based on the presence/absence of organisms detected in sea-chests was created for all vessels, and a cluster analysis and dendrogram used to explore similarities between patterns of sea-chest occupancy in relation to the three regions of vessel operation. We recognised that this overall analysis is potentially confounded by different types of vessels operating in the three regions, because sea-chest usage will differ among vessel type, which may affect occupancy. The range of vessels sampled did not allow us to look at the affect of vessel type within each region of operation, however we were able to undertake a separate analysis of sea-chest occupancy for 27 fishing vessels (the most represented vessel type) that were represented across five different regions (all of New Zealand, southern New Zealand, world-wide, Pacific and South Pacific). For this purpose, organisms

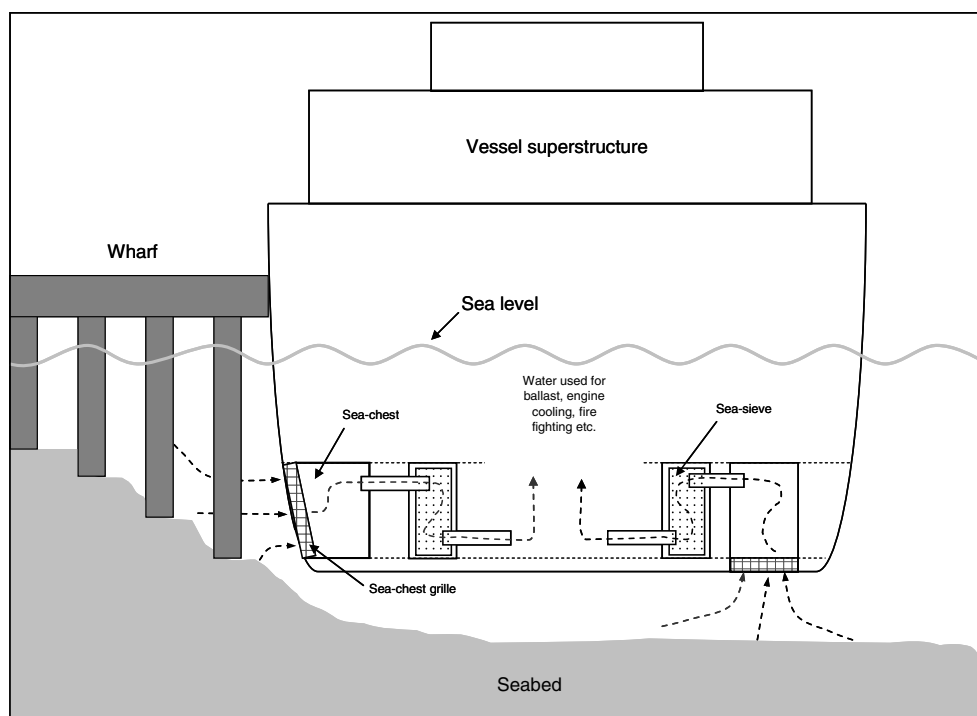


Fig. 1. Schematic diagram of a vessel's sea-chest system.

were aggregated into 22 higher taxonomic groups (i.e., Division, Phylum, or Class) to explore the main patterns in sea-chest composition among vessels from the different regions of operation. Results are displayed using a 2-dimensional non-metric multi-dimensional scaling (nMDS) ordination.

One-way Analysis of Similarity (ANOSIM; Clark, 1993) based on the presence/absence of all organisms was used to examine: (1) the similarities of organisms in sea-chests within and between vessels; and (2) factors influencing the nature and extent of organisms in sea-chests such as age of anti-fouling paint and sea-chest treatment systems, particularly with respect to organism life-habits (i.e., sessile, sedentary, mobile).

### 3. Results

#### 3.1. Occurrence of organisms in sea-chests

A total of 150 different organisms were identified from sea-chests consisting of one plant species (mangrove seeds *Avicennia marina*) and 12 animal phyla: Porifera (4 species); Cnidaria (13); Platyhelminthes (1); Nemertea (1); Nematoda (1); Mollusca (30); Ectoprocta (11); Annelida (19); Sipuncula (2); Anthropoda (43); Echinodermata (3); and Chordata (21) (Table 1). The species (taxa)-area curve analysis illustrated that the full nature and extent of organisms inside sea-chests relative to geographical regions of operation was probably not realised (Fig. 2). The curves failed to reach an asymptote, indicating that a greater range of species would have been encountered if sampling of additional sea-chests had been undertaken.

Between 1 and 33 organisms were recorded per sea-chest, with an average of  $10.7 \pm 7.1$  (mean  $\pm$  SD). The most frequently encountered taxonomic groups included Anthozoa (45% vessels), Bivalvia (74%), Ectoprocta (57%), Annelida (55%), Decapoda (79%), Thoracica (67%), and Urochordata (45%) (Table 1). Seventy-three (49%) of organisms found in sea-chests were sessile, 63 (42%) mobile adults and the remaining 14 (9%) sedentary (Table 1). Sessile organisms were present inside sea-chests of 41 (99%) vessels, a mean of  $5.6 \pm 4.2$  per vessel. Mobile organisms were present among sea-chests of 35 (83%) of vessels with a mean of  $3.3 \pm 3.6$  per vessel while sedentary organisms were present inside sea-chests of 23 (55%) vessels with an average of  $1.8 \pm 1.5$  per vessel.

Sixty (40%) organisms found in sea-chests were indigenous to New Zealand, 22 (15%) introduced, 16 (10%) non-indigenous, and 52 (35%) were of unknown origin (Table 1). The majority of the 60 indigenous organisms were present in sea-chests of domestic vessels, but many were also found in sea-chests of semi-international and international vessels (Fig. 3). Introduced organisms were particularly prevalent in sea-chests on semi-international vessels. There was a high incidence of unknown organisms among vessels from all origins. Non-indigenous organisms were most prevalent among international vessels, with 15 of the 16 taxa present in sea-chests of seven vessels from the Pacific/South Pacific region. These vessels only visited New Zealand waters at the completion of their in-service period to renew their anti-fouling paints at vessel maintenance facilities. Note that only 10 of the 15 NIMS from these international vessels were alive at the time of sampling, with five consisting of empty shells of *Cominella*

Table 1

Organisms identified inside 53 sea-chests from 42 vessels sampled in New Zealand; *Origin*: Organisms classified according to their origin relative to New Zealand waters as classified by Cranfield et al. (1998). *Life-habit*: Organisms' life-habit at the time of collection. *N* refers to the number of vessels with the organism present

Phylum/class/family	Genus/species	Origin	Life-habit	N
PLANTAE				
Avicenniaceae	<i>Avicennia marina</i> (seeds)	Indigenous	Sessile	3
PORIFERA				
Cellularia	Unidentified spp.	Unknown	Sessile	2
Callispongiidae	<i>Callispongia</i> sp.	Unknown	Sessile	2
Crellidae	<i>Crella incrustans</i>	Indigenous	Sessile	1
Sycettidae	<i>Sycon ciliata</i>	Introduced	Sessile	2
CNIDARIA				
Hydrozoa	Unidentified spp.	Unknown	Sessile	4
	<i>Amphisbetia bispinosa</i>	Indigenous	Sessile	2
Campanulariidae	Unidentified spp.	Unknown	Sessile	2
	<i>Obelia</i> sp.	Unknown	Sessile	4
	<i>Obelia dichotoma</i> (=australis)	Introduced	Sessile	1
Haleciidae	<i>Halecium</i> sp.	Unknown	Sessile	1
	<i>Halecium corrugatis</i>	Indigenous	Sessile	1
Tubulariidae	<i>Ectopleura</i> sp.	Introduced	Sessile	9
	<i>Ectopleura larynx</i>	Introduced	Sessile	3
Anthozoa				
Actiniidae	Actiniaria spp.	Unknown	Sedentary	7
	<i>Actinozoa zoantharia</i>	Indigenous	Sedentary	1
	<i>Isactina olivacea</i>	Indigenous	Sedentary	1
Sagartiidae	<i>Actinotoe albocincta</i>	Indigenous	Sedentary	1
PLATYHELMINTHES	Unidentified spp.	Unknown	Mobile	2
NEMERTEA	Unidentified spp.	Unknown	Mobile	3
NEMATODA	Unidentified spp.	Unknown	Mobile	7
MOLLUSCA				
Gastropoda	Unidentified spp.	Unknown	Mobile	1
Buccinidae	<i>Cominella</i> sp. <sup>†</sup>	Non-indigenous	Mobile	1
Fissurellidae	<i>Diodora</i> sp. <sup>†</sup>	Non-indigenous	Mobile	1
Cypraeidae	<i>Cypraea</i> sp.	Non-indigenous	Mobile	1
	<i>Cypraea</i> cf. <i>arabica</i> <sup>†</sup>	Non-indigenous	Mobile	1
	<i>Cypraea</i> cf. <i>vitellus</i> <sup>†</sup>	Non-indigenous	Mobile	1
	<i>Cypraea</i> cf. <i>marginalis</i> <sup>†</sup>	Non-indigenous	Mobile	1
Cymatiidae	<i>Cymatium</i> sp.	Unknown	Mobile	1
	<i>Cymatium gemmatum</i>	Indigenous	Mobile	1
Cavoliniidae	<i>Cavolina inflexa</i>	Indigenous	Mobile	1
Nudibranchia	Unidentified spp.	Unknown	Mobile	2
Cassinae	<i>Galeodea triganaceae</i>	Indigenous	Mobile	1
Dendrodorididae	<i>Dendrodoris citrina</i>	Indigenous	Mobile	1
Bivalvia	Unidentified sp.	Unknown	Sedentary	2
Anomiidae	<i>Anomia trigonopsis</i>	Indigenous	Sessile	1
Arcidae	Unidentified sp.	Unknown	Sessile	1
Mytilidae	<i>Mytilus</i> spp.	Introduced	Sedentary	15
	<i>Perna canaliculus</i>	Indigenous	Sedentary	19
	<i>Aulacomya atra maoriana</i>	Indigenous	Sedentary	20
Ostreidae	Unidentified spp.	Unknown	Sessile	2
	<i>Ostrea chilensis</i>	Indigenous	Sessile	3
	<i>Crassostrea gigas</i>	Introduced	Sessile	3
Pectinidae	<i>Chlamys</i> sp.	Unknown	Sedentary	1
	<i>Chlamys gemmulata</i>	Indigenous	Sedentary	3
	<i>Mesopeplum convexum</i>	Indigenous	Sedentary	1
Ungulinidae	<i>Diplodonta globus</i>	Indigenous	Sessile	1
Hiatellidae	<i>Hiatella arctica</i>	Indigenous	Sessile	13
MOLLUSCA				
Bivalvia				
Veneridae	<i>Ruditapes largillierii</i>	Indigenous	Sessile	3
Carditidae	Unidentified sp.	Unknown	Sessile	1
Gaimardiidae	<i>Gaimardia trapezina</i> <sup>†</sup>	Non-indigenous	Sessile	1

Table 1 (continued)

Phylum/class/family	Genus/species	Origin	Life-habit	N
ECTOPROCTA	Unidentified sp.	Unknown	Sessile	4
Electridae	<i>Electra tenella</i>	Introduced	Sessile	1
Bugulidae	<i>Bugula</i> sp.	Unknown	Sessile	1
	<i>Bugula flabellata</i>	Introduced	Sessile	6
	<i>Bugula neritina</i>	Introduced	Sessile	15
	<i>Bugula stolonifera</i>	Introduced	Sessile	4
Beaniidae	<i>Beania</i> sp.	Unknown	Sessile	1
Cabereidae	<i>Tricellaria catalinensis</i>	Introduced	Sessile	3
Archnopusiidae	<i>Archnopusia unicornis</i>	Indigenous	Sessile	1
Cryptosulidae	<i>Cryptosula pallasiana</i>	Introduced	Sessile	2
Watersiporidae	<i>Watersipora subtorquata</i>	Introduced	Sessile	9
ANNELIDA				
Cirratulidae	Unidentified spp.	Unknown	Mobile	2
Phyllodocidae	Unidentified spp.	Unknown	Mobile	4
Polynoidae	Unidentified spp.	Unknown	Mobile	9
Hesionidae	Unidentified spp.	Unknown	Mobile	2
Syllidae	Unidentified spp.	Unknown	Mobile	3
Nereidae	Unidentified spp.	Unknown	Mobile	14
Glyceridae	<i>Glycera tessellata</i>	Indigenous	Mobile	1
Amphinomidae	<i>Perinereis</i> sp.	Unknown	Mobile	1
Eunicidae	Unidentified spp.	Unknown	Mobile	2
Lumbrineridae	Unidentified spp.	Unknown	Mobile	1
Dorvilleidae	Unidentified spp.	Unknown	Mobile	3
Capitellidae	<i>Notomastus zelanicus</i>	Indigenous	Mobile	1
Flabelligeridae	<i>Flabelligera affinis</i>	Indigenous	Mobile	1
Terebellidae	Unidentified spp.	Unknown	Sedentary	2
Serpulidae	Unidentified sp.	Unknown	Sessile	3
	<i>Hydroides elegans</i>	Indigenous	Sessile	2
	<i>Pomatoceros terraenovae</i>	Indigenous	Sessile	1
	<i>Galeolaria hystrix</i>	Indigenous	Sessile	2
Spirorbidae	Unidentified spp.	Unknown	Sessile	1
SIPUNCULA				
Sipunculidae	Unidentified spp.	Unknown	Sedentary	1
Phascolosomatidae	<i>Phascolosma annulatum</i>	Indigenous	Sedentary	1
ARTHROPODA				
Mysidacea	Unidentified spp.	Unknown	Mobile	1
Amphipoda	Unidentified spp.	Unknown	Mobile	9
	<i>Podocerus</i> sp.	Unknown	Mobile	1
	<i>Stenothoe gallensis</i>	Non-indigenous	Mobile	1
	<i>Elasmopus rapax</i>	Non-indigenous	Mobile	1
Caprellidae	Unidentified spp.	Unknown	Mobile	8
Isopoda				
Flabellifera	Unidentified spp.	Unknown	Mobile	3
Decapoda				
Alpheidae	<i>Alpheus euphrosyne richardsoni</i>	Indigenous	Mobile	1
Palaemonidae	<i>Periclimenaeus</i> sp.	Unknown	Mobile	1
Hippolytidae	<i>Hippolytina</i> sp.	Unknown	Mobile	1
Stenopodidae	<i>Stenopus hispidus</i>	Non-indigenous	Mobile	1
Porcellanidae	<i>Petrolisthes elongatus</i>	Indigenous	Mobile	4
	<i>Petrolisthes novaezelandiae</i>	Indigenous	Mobile	1
	<i>Petrocheilus spinosus</i>	Indigenous	Mobile	1
Majidae	<i>Notomithrax minor</i>	Indigenous	Mobile	1
	<i>Schizophrys aspera</i>	Non-indigenous	Mobile	1
Canceridae	<i>Cancer novaezelandiae</i>	Indigenous	Mobile	6
Portunidae	<i>Carupa tenuipes</i>	Non-indigenous	Mobile	1
	<i>Charybdis helleri</i>	Non-indigenous	Mobile	1
Xanthidae	<i>Pilumnus novaezelandiae</i>	Indigenous	Mobile	1
	<i>Pilumnus minutus</i>	Non-indigenous	Mobile	1
Grapsidae	<i>Plagusia chabrus</i>	Introduced	Mobile	6
Hymenosomatidae	<i>Halicarcinus innominatus</i>	Indigenous	Mobile	7
	<i>Halicarcinus planatus</i>	Indigenous	Mobile	2
	<i>Halicarcinus varius</i>	Indigenous	Mobile	2
Grapsidae	<i>Cyclograpsus lavauxi</i>	Indigenous	Mobile	1

(continued on next page)

Table 1 (continued)

Phylum/class/family	Genus/species	Origin	Life-habit	N
Pycnogonida	Unidentified sp.	Unknown	Mobile	1
Thoracica				
Lepadidae	<i>Lepas anatifera</i>	Indigenous	Sessile	9
	<i>Lepas australis</i>	Indigenous	Sessile	3
	<i>Lepas testudinata</i>	Indigenous	Sessile	4
	<i>Conchoderma</i> sp.	Unknown	Sessile	1
	<i>Conchoderma auritum</i>	Indigenous	Sessile	10
	<i>Conchoderma virgatum</i>	Indigenous	Sessile	1
Balanidae	Unidentified sp.	Unknown	Sessile	1
	<i>Megabalanus</i> cf. <i>occator</i>	Non-indigenous	Sessile	1
	<i>Notomegabalanus campbelli</i>	Indigenous	Sessile	7
	<i>Notomegabalanus decorus</i>	Indigenous	Sessile	4
	<i>Megabalanus tintinnabulum linzei</i>	Indigenous	Sessile	3
	<i>Amphibalanus</i> sp.	Unknown	Sessile	3
	<i>Amphibalanus amphitrite</i>	Introduced	Sessile	12
	<i>Amphibalanus reticulatus</i>	Non-indigenous	Sessile	1
	<i>Amphibalanus trigonus</i>	Introduced	Sessile	4
	<i>Elminus modestus</i>	Indigenous	Sessile	10
ECHINODERMATA				
Echinometridae	<i>Evechinus chloroticus</i>	Indigenous	Mobile	1
Holothuroidea	Unidentified sp.	Unknown	Mobile	1
Asteriidae	<i>Coscinasterias calamaria</i>	Indigenous	Mobile	1
CHORDATA				
Urochordata	Unidentified sp.	Unknown	Sessile	3
Polyclinidae	<i>Aplidium</i> sp.	Unknown	Sessile	2
	<i>Aplidium phortax</i>	Introduced	Sessile	1
	<i>Aplidium quadrivarium</i>	Indigenous	Sessile	1
Cionidae	<i>Ciona intestinalis</i>	Introduced	Sessile	6
Didemnidae	<i>Didemnum</i> sp.	Unknown	Sessile	3
Rhodosomatidae	<i>Corella</i> sp.	Unknown	Sessile	1
	<i>Corella eumyota</i>	Introduced	Sessile	2
Botrylliinae	<i>Botrylloides</i> sp.	Introduced	Sessile	1
Styelinae	<i>Cnemidocarpa bicornuata</i>	Indigenous	Sessile	1
	<i>Styela clava</i>	Introduced	Sessile	2
	<i>Asterocarpa</i> sp.	Unknown	Sessile	2
	<i>Asterocarpa humilis</i>	Introduced	Sessile	3
Pyuridae	<i>Pyura pachydermatina</i>	Indigenous	Sessile	8
	<i>Pyura rugata</i>	Indigenous	Sessile	1
	<i>Pyura subtorquata</i>	Indigenous	Sessile	1
	<i>Pyura suteri</i>	Indigenous	Sessile	1
Vertebrata				
Eleotrididae	<i>Grahamichthys radiata</i>	Indigenous	Mobile	1
Tripterygiidae	<i>Forsterygion varium</i>	Indigenous	Mobile	1
	<i>Forsterygion malcolmi</i>	Indigenous	Mobile	1
Engraulinae	<i>Engraulis australis</i>	Indigenous	Mobile	1

† Refers to only shells of the organisms present.

sp., *Diodora* sp., *Cypraea* cf. *arabica*, *C.* cf. *vitellus* and *C.* cf. *marginalis* (Table 1). These shells were of greater size than the grille aperture of each sea-chest, suggesting that they were alive at the time of initial occupancy.

### 3.2. Community composition of organisms in sea-chests

The composition of organisms inside sea-chests was highly diverse among vessels from different origins (Fig. 4), but relatively similar among sea-chests sampled from the same vessels than between different vessels (ANOSIM,  $R = 0.770$ ,  $P = 0.001$ ). Furthermore, the composition of organisms in sea-chests was more similar for vessels that

operated in similar geographic regions than for vessels from different regions (ANOSIM,  $R = 0.169$ ,  $P = 0.016$ ). The composition of organisms in sea-chests among the 27 fishing vessels was highly variable, although there was some evidence of greater community similarity in the fishing vessels that remained in southern New Zealand waters (Fig. 5).

Age of anti-fouling paint and greater in-service period appeared to have a significant influence on sea-chest communities, with older paints and longer in-service periods associated with greater numbers of organisms (ANOSIM,  $R = 0.223$ ,  $P = 0.030$ ). Sea-chests with treatment systems contained fewer organisms on average ( $7.0 \pm 1.1$ ) than



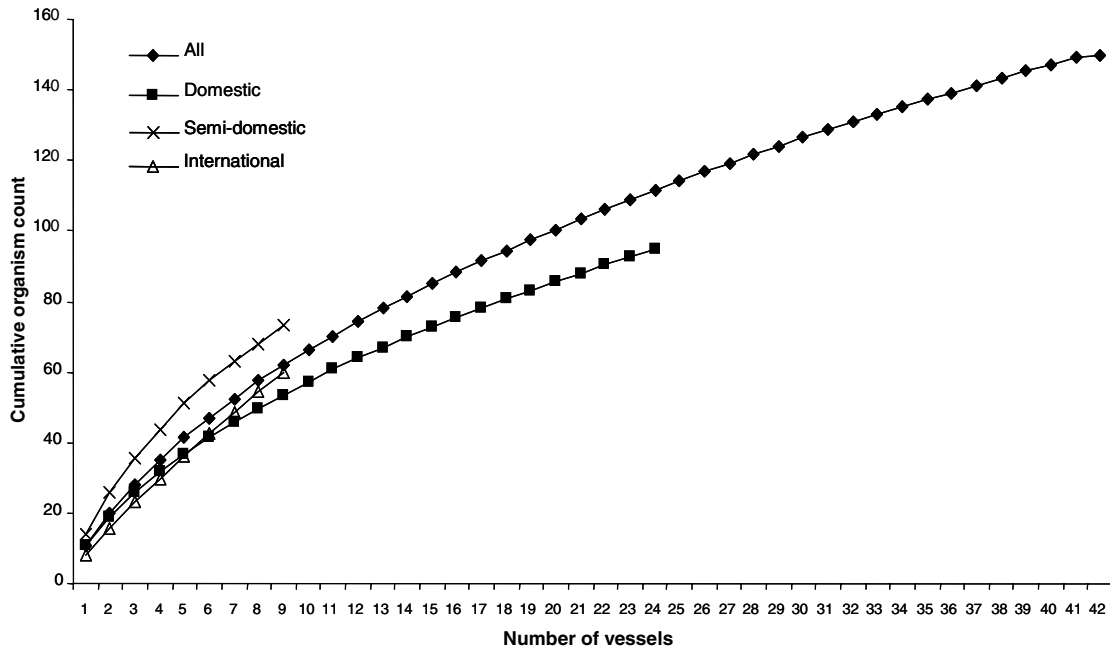


Fig. 2. Cumulative number of organisms encountered during sampling among: (1) all 42 vessels; (2) domestic vessels; (3) semi-international vessels; and (4) international vessels only.

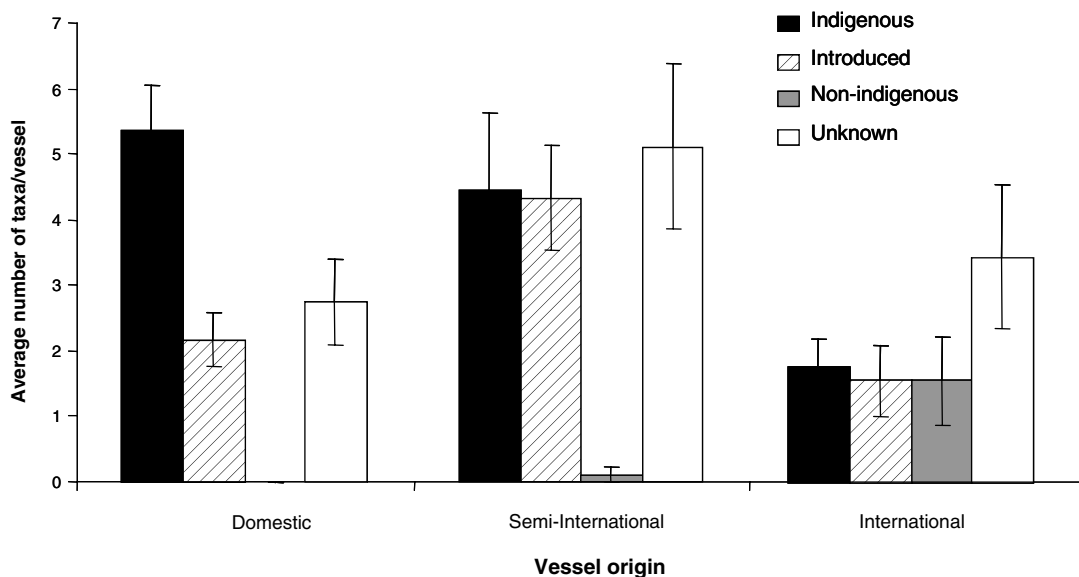


Fig. 3. Mean ( $\pm$ se) number of indigenous, introduced, non-indigenous and unknown organisms according to vessel origin (domestic, semi-international and international; see Section 2.2 for further details).

untreated sea-chests ( $11.0 \pm 1.1$ ). While treatment systems appeared to significantly influence community composition (ANOSIM,  $R = 0.233$ ,  $P = 0.009$ ), they failed to completely eliminate organisms. Furthermore, treatment systems had a significant effect on composition of both sessile (ANOSIM,  $R = 0.128$ ,  $P = 0.013$ ) and sedentary organisms (ANOSIM,  $R = 0.221$ ,  $P = 0.003$ ), but did not significantly affect the occurrence of mobile organisms in sea-chests (ANOSIM,  $R = 0.028$ ,  $P = 0.710$ ).

#### 4. Discussion

##### 4.1. Factors influencing patterns of occupancy inside sea-chests

The discovery of 150 different organisms in sea-chests of a range of vessel types from various geographical regions supports Carlton's (1992) suggestion that "sea-chests are the modern-day equivalent to the deep, sheltered cavities

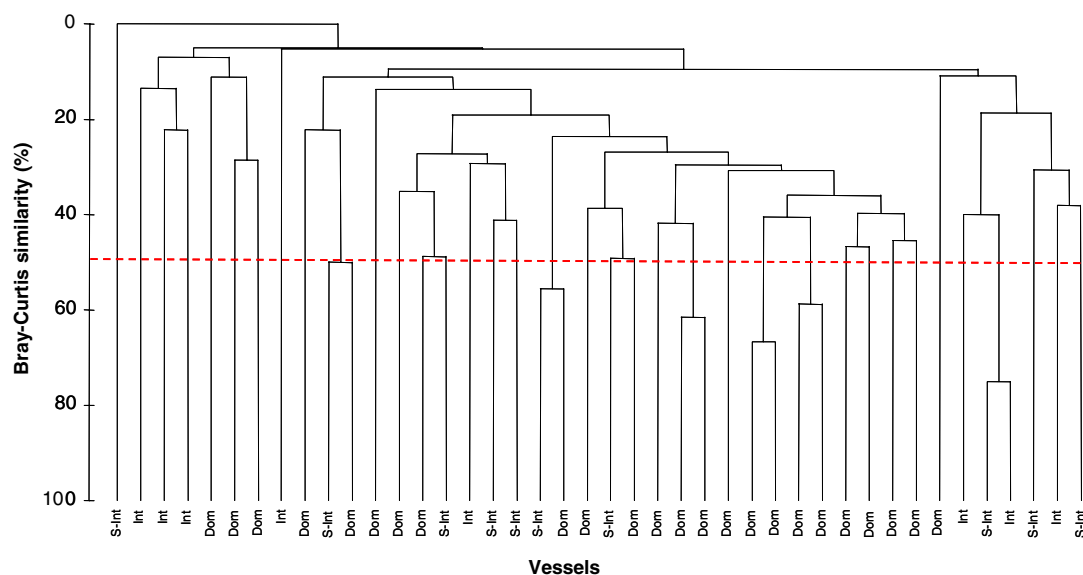


Fig. 4. Dendrogram illustrating the Bray–Curtis percentage similarity between the community composition of organisms in sea-chests of the 42 vessels surveyed. The dashed line represents the 50% similarity threshold. Int = international vessels; S-Int = semi-international vessels; Dom = domestic vessels.

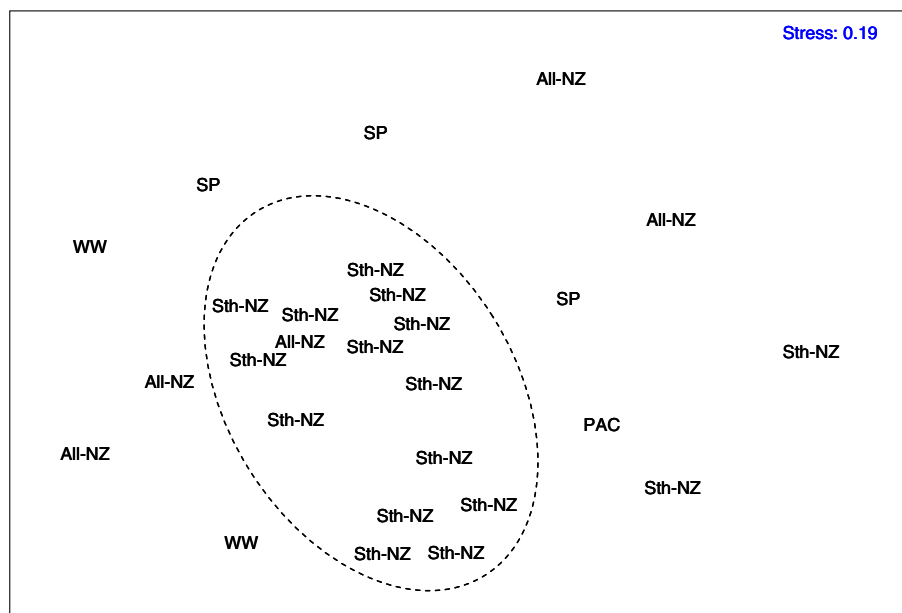


Fig. 5. Multi-dimensional scaling plot illustrating the similarity between patterns of organisms (reclassified into 22 higher taxonomic groups) in sea-chests of 27 fishing vessels relative to geographical area of operation (e.g., Sth-NZ = southern New Zealand, All-NZ = all of New Zealand, WW = world-wide, PAC = Pacific Ocean, SP = South Pacific). The dashed circle represents a group of vessels that operated in a similar geographical area.

created by shipworms in pre-20th century (wooden) vessels that provided havens for a wide diversity of adult mobile organisms". The occurrence of such diversity in sea-chests is a consequence of a variety of factors. Firstly, unlike the settlement of sessile fouling organisms on vessel hulls, many sessile, sedentary and mobile organisms are likely to be involuntarily 'vacuumed' into sea-chests from neighbouring wharf piles, the surrounding water column and even the seabed, especially when sea-chests are in close proximity to such substrata (authors unpubl. data; Fig. 1).

Secondly, anti-fouling paints in sea-chests are unable to perform as well as they do on uniform areas of the hull because they are subjected to extremes in water-flow that compromise their effectiveness. Consequently, sessile organisms are capable of establishing in areas where the paints have prematurely worn due to excessive water-flow or in static pockets where insufficient water-flow results in the paint remaining inactive. Moreover, diverse communities of sessile organisms can conceivably develop and provide suitable habitats for other organisms, particularly



mobile species (e.g., amphipods, annelids, decapods, echinoderms, gastropods and isopods). Such explanations are consistent with our observations that greater numbers of organisms were evident in sea-chests that possessed older anti-fouling paints or longer in-service periods.

Sea-chest treatment systems also significantly influenced the composition of the sea-chest communities. However, this was most evident for both sessile and sedentary organisms, with treatment having little influence on the occurrence of mobile organisms. Interestingly, other researchers have also documented the inefficacy of sea-chest treatment systems to eliminate the abundance of organisms (e.g., Lewis and Smith, 1991; Lewis et al., 1998).

Once organisms are established in sea-chests, they are likely to encounter favourable conditions for growth as they are subject to a continuous supply of food and oxygen and often elevated water temperatures (the latter due to the transfer of heat from the vessel's engine which could facilitate the survivorship of tropical organisms). Moreover, many of the mobile taxa are capable of feeding on dead organisms such as fish entrained in the sea-sieves (author's unpublished data). Most importantly, organisms inside sea-chests are protected from the unforgiving hydrodynamic flows experienced by fouling organisms on the exterior of the hull.

Our finding that the composition of organisms inside sea-chests was more similar among sea-chests sampled from the same vessel than among sea-chests from different vessels indicates that the pattern of occupancy on each vessel is relatively unique. In addition to the variety of factors that influence occupancy as described above, such findings can also be explained by the different source pool of organisms among the different regions of vessel operation. In this respect, the species (taxa)-area curve analysis highlighted the need for sampling more vessels of various types, geographical regions and origins (particularly of international origin) to capture the true nature and extent of organisms in sea-chests. Notwithstanding this need, it should be recognised that sampling effort that targets a greater source pool of organisms is likely to lead to taxonomic difficulties that may undermine the benefits of more extensive sampling. In the present study, 35% of organisms were classified as having an unknown origin because they could not be definitely described to species level.

#### 4.2. Biosecurity risk

The presence of 144 live adult organisms inside sea-chests clearly illustrates the potential for a range of taxa, particularly mobile species, to be dispersed via this mechanism. Prior to the observations made during this research, the dispersal of the 63 mobile and 14 of the sedentary organisms identified inside sea-chests in our study was assumed possible via ballast water only. Interestingly, ~95% of the mobile organisms were small enough to fit between the grilles and escape from the sea-chests sampled. Furthermore, some species such as the non-indigenous

amphipods, *Elasmopus rapax* and *Stenthor gallsensis* included females with broods of developing embryos and newly hatched juveniles. Moreover, ovigerous females of decapods were also found, including six *Halicarcinus innotatus* and one each of *Notomithrax minor*, *Pilumnus minutus* and *Plagusia chabrus*.

The occurrence of 19 different species of decapod found alive in sea-chests of 33 (79%) of the vessels suggests that sea-chests are a significant candidate for the dispersal of this group of organisms. In particular, vessels operating in the Indo-Pacific and South Pacific regions may pose a significant risk of introducing decapods while visiting maintenance facilities in New Zealand. For instance, New Zealand is already host to two Indo-Pacific decapods, the red rock crab *P. chabrus* and the swimming crab *Charybdis japonica* (Cranfield et al., 1998; Webber, 2001). Furthermore, five non-indigenous decapod species were found alive in the sea-chests of three vessels of tropical origin (Table 1) despite the vessels visiting maintenance facilities at temperate New Zealand ports (Nelson and Lyttelton) during winter. Hence it is conceivable that some of these organisms could establish in northern New Zealand waters. Moreover, there is potential for mature adult decapods to also disperse non-indigenous parasites, pathogens and viruses that may be associated with them (e.g., *Carcinonemertes epialti*, *Sacculina* spp., White Spot Syndrome Baculovirus).

Trans-Tasman vessels have the potential to introduce high profile pests from Australia to New Zealand via sea-chests. Prime candidates include the Mediterranean fanworm *Sabella spallanzanii*, the European green crab *C. maenas* and the Northern Pacific seastar *Asterias amurensis*, especially given that the latter two species have been previously recorded in sea-chests of vessels in Australia (Coutts et al., 2003; R. Thresher, pers. comm.). Conversely, international vessels are equally capable of donating indigenous New Zealand species to other regions. For example, sea-chests of trans-Tasman vessels may have contributed to the transport of the pie-crust crab (*Cancer novaezelandiae*), the pill-box crab (*H. innotatus*), the New Zealand half-crab (*Petrolisthes elongatus*) and the variable triplefin (*Forsterygion varium*) to Australia, especially given that these species were all found alive inside sea-chests during this study.

The occurrence of *F. varium* and other fish species (e.g., *Grahamichthys radiata*, *F. malcolmi*, and *Engraulis australis*) inside sea-chests is of considerable interest. The introduction of many fish species, particularly in the gobiidae and blenniidae around the world has largely been attributed to ballast water (Hoese, 1973; Springer and Gomon, 1975; Al-Hassan and Miller, 1987; Pollard and Hutchings, 1990; Willis et al., 1999; Francis et al., 2003). However, very few ballast water surveys to date have actually collected fishes (e.g., Middleton, 1982; Williams et al., 1988; Carlton and Geller, 1993; Ruiz and Hines, 1997; Smith et al., 1999). This is not surprising considering well maintained sea-sieves should prevent the passage of such

macro-organisms into ballast tanks. Therefore, although, many fish may have escaped prior to sampling conducted during this study, the presence of several fish species in our samples provides compelling evidence to suggest that sea-chests may have contributed to the dispersal of such organisms around the world.

Finally, as well as presenting a risk in the international transfer of NIMS, sea-chests may also be responsible for the spread of both indigenous and introduced species to new locations throughout New Zealand waters, and in fact throughout the domestic waters of other coastal nations. For example, a variety of domestic fishing and coastal vessels frequently travel between New Zealand ports and have the potential to disperse high profile pests such as *C. japonica* and the recently discovered (i.e., August 2005) clubbed tunicate *Styela clava* (Gust et al., 2005; Davis and Davis, 2006).

#### 4.3. Management options for sea-chests

Active anti-fouling coatings and the utilisation of effective sea-chest treatment systems are currently the best defence for mitigating the accumulation of unwanted marine growth and the biosecurity risk of sea-chest systems. A variety of treatment systems involving the release of toxic chemicals (e.g., CHLOROPAC®, Cathelco, Chem-Free™, etc.) are currently available, however they are relatively expensive and may present some environmental risk. Furthermore, our study indicates that while such treatments appear to reduce the occurrence of both sessile and sedentary organisms, they are less effective against mobile organisms such as decapods. Clearly, the treatment of biosecurity risks associated with sea-chests will require approaches that are effective against the full range of organisms that may be present. For this purpose we are currently investigating the utility of heat treatment as the most practical way forward.

The feasibility of heat treatment arises from the fact that heat can be readily generated as hot water or steam that is circulated from a vessel's engine cooling system or steam generating system. Our initial enquiries suggest that such a system would be relatively straightforward to retrofit to many vessel types. For example, 'ice-class' vessels operating in high latitudes are required to recirculate engine cooling water into at least one sea-chest to avoid freezing (e.g., Finnish-Swedish Maritime Administrations, 2005). Alternatively sea-chest hygiene could be managed via a system developed by Miko Marine AS (Norway) that enables engineers to access sea-chests from inside the vessel, thus facilitating regular in-water surveys and maintenance.

#### 5. Conclusions and recommendations

This study clearly illustrates that a wide variety of organisms are capable of surviving inside sea-chests, highlighting the potential for this mechanism to introduce NIMS and disperse indigenous and other pest organisms.

The occurrence of adult mobile stages is particularly significant and indicates that sea-chests may be of greater importance than ballast water or hull fouling for dispersing certain marine species. The actual occupancy of the sea-chests we sampled is probably even greater than reflected in our data given that many smaller organisms (<1 mm) would not have been detected and many mobile species could have escaped prior to sampling. Nonetheless, our findings emphasise the importance of managing the vessel as a whole rather than different mechanisms (i.e., ballast water, hull fouling, sea-chests, etc.) in isolation, especially if the reduction of NIMS transfer via shipping is to be a realistic goal. To further elucidate the true extent of occupancy in sea-chests we encourage researchers to undertake investigations at other maintenance facilities around the world, and to investigate a variety of other vessel types (e.g., larger ocean-going vessels) operating on different trade routes.

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#### References

- Al-Hassan, L.A.J., Miller, P.A., 1987. *Rhinogobius brunneus* (Gobiidae) in the Arabian Gulf. Japanese Journal of Ichthyology 33, 405–408.
- AMOG Consulting, 2002. Hull fouling as a vector for the translocation of marine organisms. Phase 1: Hull fouling research. Ballast Water Research Series. Report no. 14, Department of Agriculture, Fisheries and Forestry Australia, Canberra, 142 pp.
- Carlton, J.T., 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanography and Marine Biology: An Annual Review 23, 313–371.
- Carlton, J.T., 1987. Patterns of transoceanic marine biological invasions in the Pacific Ocean. Bulletin of Marine Science 41, 452–465.
- Carlton, J.T., 1992. Dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. In: Rosenfield, A.,

- Mann, R. (Eds.) Dispersal of Living Organisms into Aquatic Ecosystems. College Park, MD, pp. 13–45.
- Carlton, J.T., Reid, D.M., van Leeuwen, H., 1995. Shipping study: the role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. US Coast Guard, Connecticut, Department of Transportation, Washington, DC.
- Carlton, J.T., 1996. Pattern, process, and prediction in marine invasion ecology. *Biological Conservation* 78, 97–106.
- Carlton, J.T., 2001. Introduced species in US coastal waters: environmental impacts and management priorities. Arlington, Virginia, United States, Pew Oceans Commission, p. 28.
- Carlton, J.T., Geller, B., 1993. Ecological roulette: the global transport of nonindigenous marine organisms. *Science* 261, 78–82.
- Clark, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18, 117–143.
- Cohen, A.N., Carlton, J.T., 1995. Nonindigenous aquatic species in a United States Estuary: a case study of the biological invasions of the San Francisco Bay and Delta. A report for the United States Fish and Wildlife Services, Washington, DC and The National Sea Grant College Program, Connecticut Sea Grant. 175.
- Coutts, A.D.M., Moore, K.M., Hewitt, C.L., 2003. Ships' sea-chests: an overlooked transfer mechanism for non-indigenous marine species? *Marine Pollution Bulletin* 46, 1504–1515.
- Cranfield, H.J., Gordon, D.P., Willan, R.C., Marshall, B.A., Battershill, C.N., Francis, M.P., Nelson, W.A., Glasby, C.J., Read, G.B., 1998. Adventive marine species in New Zealand. National Institute of Water and Atmospheric Research, Technical Report 34, Wellington, New Zealand, p. 48.
- Davis, M.H., Davis, M.E., 2004. The role of man-aided dispersal in the spread of the immigrant *Styela clava* Herdman, 1882. *Journal of Marine Science and Environment* 1, 18–24.
- Davis, M.H., Davis, M.E., 2006. *Styela clava* (Tunicata: Ascidiacea) a new edition to the fauna of New Zealand. Porcupine Marine Natural History Society Newsletter 20, 23–28.
- Finnish–Swedish Maritime Administrations, 2005. Finnish–Swedish Maritime Administration Ice Classes and Requirements. <http://www.fma.fi/e/services/information/services/publications/bulletin/hae.php?l=en&s=v>.
- Fofonoff, P.W., Ruiz, G.M., Steves, B., James, J.T., 2003. In ships or on ships? Mechanisms of transfer and invasion for nonnative species to the coasts of north America. In: Ruiz, G., Carlton, J. (Eds.), *Invasive Species: Vectors and Management Strategies*. Island Press, Washington, pp. 152–182.
- Francis, M.P., Walsh, C., Morrison, M.A., Middleton, C., 2003. Invasion of the Asian goby, *Acentrogobius pflaumii*, into New Zealand, with new locality records of the introduced bridled goby, *Arenigobius bifrenatus*. *New Zealand Journal of Marine and Freshwater Research* 37, 105–112.
- Galil, B., 2000. A sea under siege – alien species in the Mediterranean. *Biological Invasions* 2, 177–186.
- Gust, N., Floerl, O., Inglis, G., Miller, S., Fitridge, I., Hurren, H., 2005. Rapid delimitation survey of *Styela clava* in the Viaduct Harbour and Freemans Bay, Auckland. NIWA Client Report CHC2005-147, National Institute of Water and Atmospheric Research Ltd., Christchurch, p. 45.
- Hayes, K.R., Sliwa, C., 2003. Identifying potential marine pests – a deductive approach applied to Australia. *Marine Pollution Bulletin* 46, 91–98.
- Hewitt, C.L., 2003. The diversity of likely impacts of introduced marine species in Australian waters. Records of the South Australian Museum Monograph Series 7, 3–10.
- Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin R.B., 1999. Marine biological invasions of Port Phillip Bay, Victoria. Technical Report No. 20, Hobart, Australia, CSIRO Marine Research, Centre for Research on Introduced Marine Pests, p. 344.
- Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B., Boyd, S., Cohen, B.F., Currie, D.R., Gomom, M.F., Keough, M.J., Lewis, J.A., Lockett, M.M., Mays, N., McArthur, M.A., O'Hara, T.D., Poore, G.C.B., Ross, D.J., Storey, M.J., Watson, J.E., Wilson, R.S., 2004. Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology* 144, 183–202.
- Hoese, D.F., 1973. The introduction of the gobiid fishes *Acanthogobius flavimanus* and *Tridentiger trigonocephalus* into Australia. *Koolewong* 2, 3–5.
- Lewis, J.A., Smith, B.S., 1991. Hydroids settlement in Sydney Harbour (Australia) and its control in sea-water cooling systems. In: Rossmore, H.W. (Ed.), *Biodeterioration and Biodegradation*, vol. 8. Elsevier Applied Science, London, pp. 464–466.
- Lewis, J.A., Smith, B.S., Taylor, R.J., Batten, J.J., 1998. Fouling of RAN submarine seawater systems and a comparison of electro-chemical control methods. In: Proceedings of the 8th International Naval Corrosion Conference, Plymouth, United Kingdom, April 1998, Paper no. 7, pp. 1–19.
- Middleton, M.J., 1982. The oriental goby, *Acanthogobius flavimanus* (Temminck and Schlegel), an introduced fish in the coastal waters of New South Wales, Australia. *Journal of Fish Biology* 21, 513–523.
- Minchin, D., Gollasch, S., 2002. Vectors – how exotics get around. In: Leppäkoski, E., Gollasch, S., Olenin, S. (Eds.), *Invasive Aquatic Species of Europe: Distribution, Impacts and Management*. Kluwer Academic Publishers, Netherlands, pp. 183–192.
- Nehring, S., 2002. Biological invasions into German waters: an evaluation of the importance of different human-mediated vectors for nonindigenous macrozoobenthic species. In: Leppäkoski, E., Gollasch, S., Olenin, S. (Eds.), *Invasive Aquatic Species of Europe: Distribution, Impacts and Management*. Kluwer Academic Publishers, Netherlands, pp. 373–383.
- Newman, W., 1963. On the introduction of an edible Oriental shrimp (Caridea, Palaemonidae) to San Francisco Bay. *Crustaceana* 5, 119–132.
- Pimentel, D., Lach, L., Zuniga, R., Morrison, D., 2000. Environmental and economic costs of non-indigenous species in the United States. *BioScience* 50, 53–65.
- Pollard, D.A., Hutchings, P.A., 1990. A review of exotic marine organisms introduced to the Australian region II. Invertebrates and algae. *Asian Fisheries Science* 3, 223–250.
- Richards, A., 1990. Muricids: A Hazard to Navigation? *Hawaiian Shell News* May, p. 10.
- Ruiz, G.M., Hines, A.H., 1997. The risk of nonindigenous species invasion in Prince William Sound associated with oil tanker traffic and ballast water management: pilot study. Regional Citizens' Advisory Council of Prince William Sound, Valdez, Alaska (Rep. No. 632f.97.1).
- Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonham, M.J., Hines, A.H., 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. *Annual Reviews in Ecology and Systematics* 31, 481–531.
- Schormann, J., Carlton, J.T., Dochoda, M.R., 1990. The ship as a vector in biotic invasions. *Marine Technology and the Environment* 19, 147–152.
- Sinner, J., Forrest, B.M., Taylor, M.D., 2000. A Strategy for Managing the Asian Kelp *Undaria*: Final Report. Cawthron Report, 578, Cawthron Institute, Nelson, New Zealand, 122p.
- Slack-Smith, S.M., Brearly, A., 1987. *Musculista senhousia* (Benson, 1842); a mussel recently introduced into the Swan River estuary, Western Australia (Mollusca: Mytilidae). *Records of the Western Australian Museum* 13, 225–230.
- Smith, L.D., Wonham, M.J., McCann, L.D., Ruiz, G.M., Hines, A.H., Carlton, J.T., 1999. Invasion pressure to a ballast-flooded estuary and an assessment of inoculant survival. *Biological Invasions* 1, 67–87.
- Springer, V.G., Gomom, M.F., 1975. Revision of the Blenniid fish genus *Omobranchus* with descriptions of three new species and notes on other species of the tribe Omobranchini. *Smithsonian Contributions to Zoology* 177, 1–135.
- Thresher, R.E., Hewitt, C.L., Campbell, M.L., 1999. Introduced and cryptogenic species in Port Phillip Bay. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), *Marine Biological Inva-*

- sions of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No. 20 CSIRO Marine Research, Hobart, pp. 283–295.
- Webber, R., 2001. Space invaders, crabs that turn up in New Zealand unannounced. Seafood New Zealand, 80–84.
- Williams, R.J., Griffiths, F.B., van der Waal, E.J., Kelly, J., 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. *Estuarine and Coastal Shelf Science* 26, 409–420.
- Willis, T.J., Saunders, J.E.H., Blackwood, D.L., Archer, J.E., 1999. First New Zealand record of the Australian bridled goby, *Arenigobius bifrenatus* (Pisces: Gobiidae). *New Zealand Journal of Marine and Freshwater Research* 33, 189–192.
- Wonhom, M.J., O'Connor, M., Harley, C.D.G., 2005. Positive effects of a dominant invader on introduced and native mudflat species. *Marine Ecology Progress Series* 289, 109–116.